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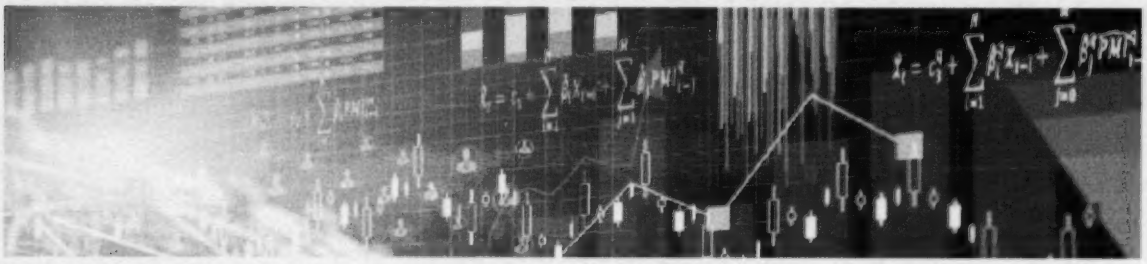
A Bitcoin Standard: Lessons from the Gold Standard



by Warren E. Weber

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A Bitcoin Standard: Lessons from the Gold Standard

by

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Abstract

This paper imagines a world in which countries are on the Bitcoin standard, a monetary system in which all media of exchange are Bitcoin or are backed by it. The paper explores the similarities and differences between the Bitcoin standard and the gold standard and describes the media of exchange that would exist under the Bitcoin standard. Because the Bitcoin standard would closely resemble the gold standard, the paper explores the lessons about how it would perform by examining the classical gold standard period, specifically 1880–1913. The paper argues that because there would be virtually no arbitrage costs for international transactions, countries could not follow independent interest rate policies under the Bitcoin standard. However, central banks would still have some limited ability to act as lenders of last resort. Based on the experience during the classical gold standard period, the paper conjectures that there would be mild deflation and constant exchange rates under the Bitcoin standard. The paper also conjectures how long the Bitcoin standard might last if it were to come into existence.

JEL classification: E, E4, E41, E42, E5, E58
Bank classification: E-money; Financial services; Exchange rates; Inflation and prices

Résumé

Dans ce document, nous imaginons un monde où le bitcoin est la monnaie étalon des pays, soit un système monétaire au sein duquel tous les échanges se font au moyen du bitcoin ou sont garantis par celui-ci. Nous décrivons la manière dont se feraient les échanges sous le régime d'étalon-bitcoin, et explorons les similitudes et les différences avec l'étalon-or. Étant donné que les deux régimes se ressembleraient beaucoup, nous tentons de déterminer les leçons que l'on pourrait tirer de l'utilisation du bitcoin comme étalon en examinant la période de l'étalon-or classique (de 1880 à 1913). Nous soutenons que, puisque les coûts liés à l'arbitrage seraient pratiquement nuls pour les opérations internationales, les pays ne pourraient pas suivre de politique indépendante en matière de taux d'intérêt sous l'étalon-bitcoin. Cependant, les banques centrales conserveraient une capacité limitée de jouer le rôle de prêteur de dernier ressort. En nous basant sur l'expérience vécue pendant la période de l'étalon-or classique, nous supposons que l'adoption du bitcoin comme étalon entraînerait une légère déflation et une stabilisation des taux de change. Nous estimons également la durée probable d'un tel régime.

Classification JEL : E, E4, E41, E42, E5, E58
Classification de la Banque : Monnaie électronique; Services financiers; Taux de change; Inflation et prix

Non-Technical Summary

Interest in Bitcoin and the use of Bitcoin as a medium of exchange has been growing worldwide. This paper extrapolates the growth of Bitcoin as a medium of exchange and conducts the following thought experiment: Suppose that the use of Bitcoin has grown to such an extent that it has replaced existing fiat currencies and has become the predominant medium of exchange or at least the backing for the predominant medium of exchange in a large group of countries. I will call a monetary system *the Bitcoin standard*, because such a monetary system will very likely be similar to the gold standard.

The two standards are similar in that changes in the supply of the anchor of the monetary system are not under the control of any central bank or monetary authority. Changes in the supply of Bitcoin are set deterministically by the algorithm that governs how many new Bitcoins "miners" receive for verifying Bitcoin transactions and adding them to the blockchain. Changes in the world stock of gold were determined by gold discoveries and the invention of new techniques for extracting gold from gold-bearing ores.

Just as three distinct media of exchange existed under the gold standard, three distinct media of exchange are assumed to exist under the Bitcoin standard: Bitcoin, fiduciary currencies issued by countries' central banks, and fiduciary currencies (bank notes or deposits) issued by commercial banks.

The scope of monetary policy would be more limited under the Bitcoin standard than under the gold standard. The ability to issue fiduciary currency would give central banks limited ability to act as lenders of last resort. However, virtually costless arbitrage of Bitcoin across countries would prevent central banks from implementing interest rate policies to affect their domestic economies.

An empirical examination of countries' experience with the gold standard leads to the following conjectures about how the Bitcoin standard might perform:

1. In the long run, there would be moderate deflation that would increase over time until reaching a rate of deflation equal to the negative of the rate of growth of world output around 2026.

2. Price levels of the various countries would be highly, but not perfectly, correlated, much as they were under the gold standard.

3. Exchange rates among the fiduciary currencies of various countries would be fixed at par, because the cost of Bitcoin arbitrage is essentially zero.

4. There would still be financial crises, because they can occur under any fractional reserve financial system.

The paper concludes by speculating that even if the Bitcoin standard were to come into existence, it would not last long, for two reasons: (1) The payments world is changing so rapidly that there will be a technological innovation that provides a potential medium of exchange with the same or greater benefits of Bitcoin or with lower costs. Such an innovation could come either from the private sector or from the government. (2) There would be pressure to return to a fiat money system so that a more activist monetary policy could be pursued.

1 Introduction

Of the approximately 700 cryptocurrencies in existence today, Bitcoin is by far the most well-known, and its use as a medium of exchange has been growing worldwide.[1] According to CoinDesk, as of 15 September 2015 there are 11.05 million Bitcoin wallets, 106,000 merchants who accept Bitcoin payments and 475 Bitcoin automated teller machines (ATMs). These numbers are substantially larger than the 6.56 million Bitcoin wallets, 76,000 merchants who accepted Bitcoin payments and 238 Bitcoin ATMs as of 14 September 2014. Some merchants that accept Bitcoin are Microsoft, which began accepting Bitcoin as payment for games, apps, and videos in December 2014; Dell, which started accepting Bitcoin as payment in Canada, the United Kingdom, and the United States in February 2015; DISH Network; and Overstock.com. Further, in November 2015 it was announced that a Visa Bitcoin debit card would be introduced that would allow users to "spend Bitcoin both online and at physical points of sale at more than 38 million merchants worldwide."[2] Bitcoin also has been the subject of numerous articles in the media. For example, a headline in the *New York Times* on 4 November 2015 announced that "Bitcoin Surges, Emerging From a Lull in Interest."

In this paper I extrapolate the growth of Bitcoin as a medium of exchange and conduct the following thought experiment: Suppose that the use of Bitcoin has grown to such an extent that it has replaced existing fiat currencies and has become the predominant medium of exchange or at least the backing for the predominant medium of exchange in a large group of countries. I will call a monetary system in which Bitcoin is the common backing for the payments systems in a number of countries *the Bitcoin standard*. I choose this terminology because such a monetary system will very likely be similar to the gold standard. The gold standard was a monetary system in which countries' currencies were tied to gold. The Bitcoin standard of my thought experiment is a monetary system in which countries' currencies are tied to Bitcoin.

There may be some skepticism at this point as to how the Bitcoin standard would ever be adopted, even by a single country. A major reason for this skepticism is the fluctuations in the price of Bitcoin relative to the U.S. dollar since its inception in 2009. The price of Bitcoin relative to the dollar from January 2013 through the middle of August 2015 is shown in Figure 1. As the figure shows, Bitcoin went from about $13 per Bitcoin on 1 January 2013 to a high of almost $1,150 per Bitcoin on 30 November of that year. Thus far during 2015, the price of a Bitcoin has ranged between $175 and $315, with prices centred around $225.

Although the skepticism about whether the Bitcoin standard could come into being is warranted to some extent, it must be remembered that if currencies other than Bitcoin exist under the Bitcoin standard, the fluctuations of their prices in terms of Bitcoin will be limited or eliminated: these currencies will be tied to Bitcoin in the sense that they will be redeemable in Bitcoin on demand. This is not the case for current fiat currencies vis-a-vis Bitcoin. Thus, the current experience with the price of Bitcoin in terms of dollars is not

[1] A cryptocurrency is one in which users come to an agreement about changes in the transactions ledger using cryptographic techniques. In the case of Bitcoin, the unique private key associated with every Bitcoin transaction is encrypted.

[2] Giulio Prisco, "Coinbase and Shift Payments Introduce a Visa-branded Bitcoin Debit Card That Works Everywhere Visa is Accepted," *Bitcoin Magazine*, 24 November 2015.

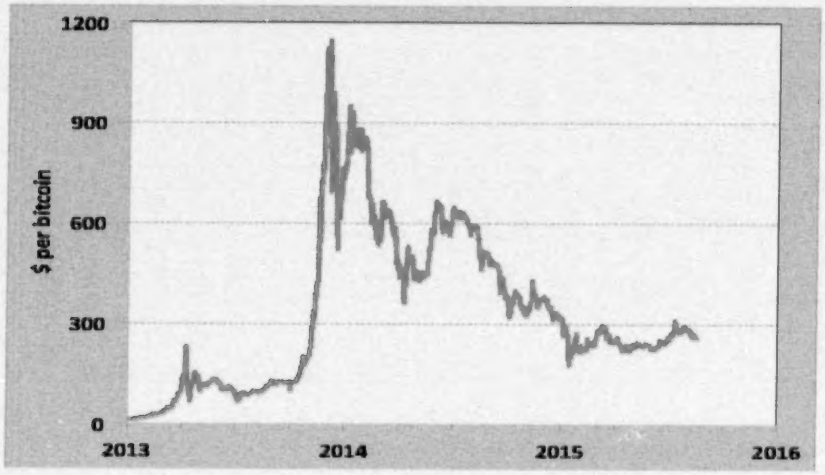

Figure 1: $ per Bitcoin, January 2013 to August 2015

relevant for how goods prices in terms of Bitcoin (the price level in terms of Bitcoin) would behave under the Bitcoin standard.

The purpose of this paper is to examine the historical experience with the gold standard to determine what lessons can be learned about what the experience might be if a Bitcoin "anchored monetary system" similar to the gold standard were to come into existence. The purpose in this paper is not to do a welfare analysis of whether the Bitcoin would be better or worse than current monetary arrangements. Nor is the purpose to advocate that the Bitcoin standard be adopted.

The paper proceeds as follows: In section 2, I describe in more detail the Bitcoin standard and the media of exchange that would exist under it. I also discuss some differences between the Bitcoin standard and the gold standard that arise due to the differences between Bitcoin and gold. In section 3, I discuss how monetary policy could be conducted under the Bitcoin standard and how it would differ from the conduct of monetary policy under the gold standard. In section 4, I present evidence on how prices, exchange rates, and real output behaved under the gold standard, and, based on this evidence, I conjecture about how these variables would behave under the Bitcoin standard. In this section I also present evidence on how many financial crises occurred under the gold standard and conjecture about whether there would also be financial crises under the Bitcoin standard. In Section 5, I speculate about how stable the Bitcoin standard would be if it were to come into being. Section 6 concludes. Why the gold standard came into existence and more details about how it worked are presented in Appendix I. Data sources are given in Appendix II.

2 The Bitcoin Standard

In order to set the stage for a discussion of how monetary policy might be conducted under my imagined Bitcoin standard and what the outcomes might be in terms of price levels, exchange rates, real output and financial crises, I discuss the Bitcoin standard in more detail in this section. I begin by discussing how the Bitcoin standard is similar to and different from the gold standard. I then discuss the media of exchange that would exist under the Bitcoin standard and relate them to the media of exchange that existed under the gold standard.

The most important similarity between the Bitcoin standard and the gold standard is that no central bank or monetary authority controls the supply, or more importantly, changes in the supply of the anchor of the monetary system. Changes in the supply of Bitcoin are set deterministically by the algorithm that governs how many new Bitcoins "miners" receive for verifying Bitcoin transactions and adding them to the blockchain. In the case of gold, changes in the world stock of gold were determined by gold discoveries and the invention of new techniques for extracting gold from gold-bearing ores.

There is also a major difference. Increases in the stock of Bitcoin are deterministic and, therefore, predictable. The Bitcoin algorithm determines the rate at which new Bitcoins are created at each point in time until the limit of 21 million Bitcoins is reached in 2140. In contrast, increases in the quantity of the world gold stock over time were not predictable due to the unpredictability of gold discoveries and changes in world gold production. As I will show later, there were large year-to-year fluctuations in the rate of increase of the world gold stock.

I assume that three different media of exchange exist under the Bitcoin standard, just as three different media of exchange existed under the gold standard. The first of these is Bitcoin itself; that is, actual amounts of the anchor of the monetary system. Bitcoin plays a role in the payments system similar to that played by coins under the gold standard.[3]

The second media of exchange under the Bitcoin standard are fiduciary currencies issued by each country's monetary authority. That is, central banks or government treasuries issue currencies that are not 100 percent backed by Bitcoin, but are redeemable in some specified amount of Bitcoin on demand.

Given the usefulness of Bitcoin as a medium of exchange, it is possible that the Bitcoin standard could exist without each country's monetary authority issuing a fiduciary currency. Nonetheless, I assume that monetary authorities choose to issue fiduciary currencies in order to have the ability to finance fiscal deficits through money creation. Further, I make this assumption to have the media of exchange under the Bitcoin standard be similar to those under the gold standard, because each country issued its own fiduciary currency under the gold standard. For example, in the United Kingdom, the Bank of England issued bank notes that had to be redeemed in a specific amount of gold on demand. In the United States, the Treasury issued U.S. notes, and later, the Federal Reserve System issued Federal Reserve

[3]The necessity for coins under the gold standard is that "raw" gold is not a convenient medium of exchange. The weight and fineness of the amount of gold being offered in a transaction have to be verified, which can be time consuming and costly. These costs were reduced by governments establishing mints that produced coins of a known weight and fineness. In contrast, a Bitcoin is a Bitcoin. No verification is required.

notes. Both were redeemable in gold on demand. In Canada, the Treasury issued Dominion notes, which were also redeemable in gold.

Thus, I assume that in addition to Bitcoin, there are Bank of Canada dollars, Federal Reserve dollars, European Central Bank (ECB) euros, Bank of England pounds and so forth.[4] These central bank currencies are separate currencies that circulate alongside Bitcoin. They are tied to Bitcoin because they are redeemable in Bitcoin on demand. These central bank currencies are fiduciary because the central banks would not be required to fully back their issues with Bitcoin, just as under the gold standard central banks did not fully back their note issues with gold.

These fiduciary currencies appear as liabilities on the balance sheets of the central banks under two headings, just as fiduciary currencies did under the gold standard and fiat currencies do today. The first heading is the accounts that central banks set up on their ledgers for commercial banks in their countries. These accounts are denominated in terms of the central banks' individual currencies and exist solely on the ledger of the central bank; they are not part of the decentralized Bitcoin blockchain. Commercial banks use these accounts for settlement or reserve purposes similar to how today banks in Canada use the deposit accounts at the Bank of Canada labelled "Members of the Canadian Payments Association" and how banks in the United States use the accounts at the Federal Reserve Banks labelled "Term deposits held by depository institutions."

The second heading on the balance sheets is the one that pertains to the fiduciary currency in circulation in the hands of the non-bank public. These accounts are similar to the Bank of Canada's "Bank notes in circulation" and the Federal Reserve banks' "Federal Reserve notes" headings. Under the Bitcoin standard, the form of the fiduciary currency in circulation with the non-bank public could be paper (or plastic or perhaps some metallic alloy like today's coins) and/or digital form. Of course, there are certain considerations involved in the issuance of central bank non-digital currencies, such as the choice of the minimum denomination and of the number of denominations. However, although these choices are significant, they do not affect how the Bitcoin standard works.

The redemption of these fiduciary currencies takes the form of transferring Bitcoins from the central bank's "wallet" to the "wallet" of the commercial bank or person requesting the withdrawal rather than transferring gold coins or bullion as was the case under the gold standard.

Under the Bitcoin standard, the private banking system continues to exist and engages in maturity transformation in the sense that banks do not hold assets with the same maturities as their liabilities. However, there is the question about whether banks issue callable liabilities; that is, whether banks issue bank notes or take callable deposits. I assume that they do so under the Bitcoin standard, and that, as was the case under the gold standard, these callable liabilities are not fully backed. These callable liabilities of banks are the third media of exchange I assume exist under the Bitcoin standard. Once again, I make this assumption so that the media of exchange under the Bitcoin standard and under the gold standard are similar.[5]

[4] If countries did not have their own monetary units, there would be Bank of Canada Bitcoin, Federal Reserve Bitcoin, ECB Bitcoin, Bank of England Bitcoin and so forth. Whether countries have their own monetary units or have Bitcoin as the monetary unit does not matter for the analysis.

[5] See Wallace (1996) for a theoretical model in which a fractional reserve banking system is superior to

The question arises, In what form would the bank notes or deposits be redeemable? There are three possibilities:

1. Central bank fiduciary currency (for ease of exposition call them dollars) only. Banks' reserves against these deposits are dollar deposits at the central bank and dollars held in their vault (vault cash). Banks do not hold any Bitcoin reserves against these accounts because they are not required to pay out Bitcoin. Interbank clearing is done as clearing is done with cheques today.

2. Bitcoin only. Banks' reserves against Bitcoin deposits are held in "wallets" in which they hold Bitcoin. Most likely, these bank "wallets" would be provided by the private sector rather than by a central bank. It is unlikely that central banks would offer such wallets unless there was a public policy case that central bank-provided wallets would be more secure than those provided by the private sector.[6]

3. Bitcoin or dollars. I leave open the question of whether the form of payout to a liability holder is at the holder's or the bank's discretion.[7]

Under the Bitcoin standard, Bitcoin held in an agent's wallet serves all the functions that banks' callable liabilities serve. Consequently, agents would not see the need to have or use the callable liabilities of the bank that were redeemable in Bitcoin. This argues for the proposition that the only type of callable liability offered by banks under the Bitcoin standard is the dollar-only one.

3 Monetary Policy Under the Bitcoin Standard

There are two types of monetary policy to be considered. The major one is interest rate policy: the ability to change interest rates to affect the domestic economy. The other is the ability to act as a lender of last resort by providing reserves to the banking system in times of financial crisis. The ability to carry out monetary policy differs under the two standards. Central banks had greater ability to carry out monetary policy under the gold standard than they would have under the Bitcoin standard. In this section, I explain why this is the case.

a narrow banking system.

[6]Clearing deposit Bitcoin-only accounts would be complex because only one of the two verifications necessary to avoid the "double-spending problem" can be done using the decentralized ledger. The verification that the bank has in its wallet the amount of Bitcoin to be transferred can be done in the blockchain. However, verification that the writer of the cheque has the amount of Bitcoin to be transferred in their account cannot be done in the blockchain, since some or all of the Bitcoin in the account may have been "created" by some financial institution.

[7]When cheques are written in terms of Bitcoin on these accounts, the same clearing issues arise as those with Bitcoin-only accounts. There is the further problem that agents have to be able to do the dollar-to-Bitcoin conversion when writing cheques to be certain that they do not overdraft their accounts. Of course, this problem can be mitigated somewhat if the monetary unit is chosen to be convenient; for example, a dollar is equal to 0.1 Bitcoin.

Interest Rate Policy

Under the gold standard, interest rate policy worked through bank rates (discount rates), or, more correctly, because the monetary authority in a country could set its bank rate different from that in other countries. Countries had some latitude to raise or lower their bank rate to raise or lower interest rates generally in their country, and in this way affect the domestic economy.

One might think that monetary authorities would not have this ability, because gold arbitrage would work to equate interest rates across countries. Gold would flow to the country where it would earn the highest rate of return and that would limit the differences in interest rates among countries on the gold standard. However, gold arbitrage could not eliminate differences entirely, because gold arbitrage was costly. The presence of costs to gold arbitrage gave monetary authorities some independence in setting interest rates in their country.

To see how this process worked, consider the case in which the monetary authority in Country A wanted to raise its bank rate, r_A, to cool down the economy. An agent in Country B who has one ounce of gold faces the question of whether to invest the gold domestically or export it to Country A.[8] If the agent invests domestically, the gold earns r_B, the bank rate in Country B. If, instead, the agent exports the gold to Country A, the gold earns $r_A - k$, where k is the per ounce time, shipping and insurance cost of sending gold from Country B to Country A. If $r_A - k > r_B$, gold will be shipped to Country A. The influx of gold will increase the reserves of the banking system in Country A and increase the money supply in Country A as banks increase their lending in response to the higher level of reserves. Thus, the monetary authority in Country A cannot set its bank rate too high. Otherwise, the resulting gold inflow will offset what they were attempting to achieve by raising the bank rate.

Using analogous reasoning, the monetary authority in Country A faced a constraint on how much it could lower its bank rate to stimulate the economy. Consider an agent in Country A who has one ounce of gold. This agent faces the question of whether to invest the gold domestically or export it to Country B and invest it there. If the agent invests domestically, the gold earns r_A. If the agent exports the gold to Country B and invests it there, the gold earns $r_B - k$. Thus, if $r_A < r_B - k$, gold will be shipped out of Country A. The outflow of gold will decrease the reserves of the banking system in Country A and decrease the money supply in Country A as banks decrease their lending in response to the lower level of reserves. Thus, the monetary authority in Country A cannot set its bank rate too low. Otherwise, the resulting gold outflow will offset what they were attempting to achieve by lowering the bank rate.

Combining these two arguments, the latitude that the monetary authority in Country A had with regard to setting its bank rate was[9]

[8]The discussion of the mechanism here is similar to the discussion of the price-specie flow mechanism except that here the other side of the arbitrage is capital whereas it was commodities in the case of the price-specie flow mechanism.

[9]Restriction (1) also shows that countries faced the consequences of discount rate actions taken by monetary authorities in other countries. During the classical gold standard period, the major player was the Bank of England; changes in its discount rate had major effects on the gold reserves, and consequently on the economies of the other countries on the gold standard.

$$\underbrace{r_B - k}_{\text{no gold outflows}} < r_A < \underbrace{r_B + k}_{\text{no gold inflows}} . \quad (1)$$

Thus, the cost of gold arbitrage in effect determined a policy corridor in which a central bank could set its bank rate different from other bank rates.[10] Officer (1996, Table 10.2) computes the range for the U.K. pound sterling and the U.S. dollar to be between 100 and 140 basis points.[11] The empirical evidence in Bordo and MacDonald (2005) shows that under the gold standard short-term interest rates differed across the United Kingdom and France and the United Kingdom and Germany.

Under a Bitcoin standard, however, it will not be possible for a country to conduct an interest rate policy to affect domestic economic conditions. As (1) shows, it was the cost of engaging in gold arbitrage that allowed a country to set a bank rate that differed from those in other countries under the gold standard. Such arbitrage costs do not exist for the Bitcoin standard; that is, $k = 0$. The costs of arbitrage between the fiduciary currencies of any two central banks are essentially zero. The time cost of obtaining Bitcoin for fiduciary currency or fiduciary currency for Bitcoin would be extremely small, and because the ledger containing transactions history is open and transactions are recorded regardless of location, no shipping or insurance costs are involved. Thus, the spot exchange rates for all fiduciary currencies would be one-to-one, and monetary authorities would be unable to set interest rates different from those in other countries.

Lender of Last Resort

The ability of monetary authorities to issue fiduciary currencies under the gold standard enabled them to act as lenders of last resort when there were runs on commercial banks, because these currencies could serve as reserves for the banking system. The policy tools for acting as a lender of last resort were determination of the collateral eligible for discounting and the haircut on that collateral. The same mechanism enables central banks to act as lenders of last resort when there are bank runs under the Bitcoin standard.

A stylized description of how a central bank acted as lender of last resort in a financial crisis under the gold standard and can act under the Bitcoin standard is the following. Financial institutions have reserve accounts on the central bank's books. When they face runs on their notes or deposits and are in danger of running short of reserves, the central bank can supply financial institutions with reserves by purchasing ("discounting") commercial paper and other assets presented by commercial banks with its own fiduciary currency. Because these reserves are in terms of the central bank's fiduciary currency, the central bank does not have to possess the amount of gold or Bitcoin equal in value to the amount that it credits to the commercial bank before making the transaction. Because the central bank does not

[10]This explanation for (1) as the restriction on a central bank's interest differs from that given by Bordo and MacDonald (2005), which relies on expectations of exchange rate movements. However, both explanations arrive at the same implications for the range in which a central bank could set its bank rate without gold flows occurring.

[11]The existence of the Atlantic cable might suggest that the band (1) would be much smaller. However, Officer (1996, 114) argues that cable transfers were "an instrument that in historical fact was eschewed by arbitrageurs and transferors."

have to make the discount purchases by paying out gold or paying out Bitcoin, it can simply create reserves for banks.

Should financial institutions have to meet withdrawal demands by depositors, they would draw on their reserve account with the monetary authority and obtain the paper or digital form of the central bank's fiduciary currency. Because these fiduciary currencies are accepted as media of exchange, they would most likely satisfy depositors' withdrawal demands.

That central bank fiduciary currencies are redeemable on demand in gold or Bitcoin opens up the possibility of runs on central banks because of concerns about their ability to meet demand. The possibility of such runs means that a central bank can only issue its fiduciary currency up to a point. The ability of a monetary authority to act as lender of last resort under either the gold or Bitcoin standard is limited. This is in contrast with the almost unlimited ability of central banks to act as lenders of last resort under a fiat monetary standard.[12]

Facing such a run on its fiduciary currency, a central bank is limited in what it can do because it cannot act as the lender of last resort to itself. There are two possible actions it can take. One is to suspend payments, as the Bank of England did in 1791. The problem with this action is that unless there is a credible commitment to redeem in the future, existing fiduciary currency will very likely depreciate in value and the central bank may never be able to issue fiduciary currency again. The other possibility is to borrow Bitcoin from other central banks with the promise to repay once the crisis it faces abates. An example: the Bank of France loaned gold to the Bank of England during the Baring crisis of 1890.[13]

Caveat

Under a Bitcoin standard, the stock of Bitcoin in a country can be affected by government action. The government could collect taxes in the form of Bitcoin, or the government could sell bonds for Bitcoins. If the proceeds from these actions are not subsequently spent, then the quantity of Bitcoin in the country would be reduced, which should serve to reduce bank reserves and the country's money supply. However, such actions are more properly considered fiscal policy rather than monetary policy.[14]

4 How Would the Bitcoin Standard Perform?

In this section, I examine the classical gold standard period (specifically, 1880 - 1913) to conjecture how the Bitcoin standard might perform with respect to price levels, exchange rates, real output growth and financial crises. In making these conjectures, I take both the similarities and differences between the two standards into account.

[12] I say almost because all fiat money economies have at least two equilibria, one of which is that the fiat money is not valued. If agents in the economy expect that the amount of fiat money issued by the central bank acting as lender of last resort would be too large, then the economy might switch to the equilibrium in which the fiat money is not valued.

[13] For a discussion of other instances of central banks lending gold to other central banks, see Eichengreen (1992).

[14] Under a gold coin standard, a monetary authority can choose the number of different coins, how much gold is in each and the seigniorage rate. These decisions could be considered monetary policy. However, since Bitcoin is digital and expressed to eight decimal places, such possibilities are not relevant for the discussion here.

Price Levels

The price data for a sample of 11 countries on the gold standard between 1880 and 1913 reveal four facts:

1. Countries experienced very little inflation when the period 1880 to 1913 is considered as a whole. In the second column of Table 1, I show the average inflation rates for the sample countries for the entire period.[15] The rates of inflation over the entire period were less than 1 percent in absolute value for all 11 countries.

	Average			
Country	1880 - 1913	1880 - 1895	1895 - 1913	Std. Dev.
Belgium	0.06	-1.87	1.67	3.79
Canada	0.77	-0.89	2.15	3.86
Denmark	-0.25	-1.12	0.48	2.64
France	0.05	-0.53	0.74	3.43
Germany	0.42	-1.26	1.83	4.73
Netherlands	0.17	-0.53	0.74	1.93
Norway	0.62	-0.81	1.82	2.83
Sweden	0.29	-1.75	1.98	3.83
Switzerland	-0.07	-1.92	1.47	3.81
United Kingdom	-0.32	-2.35	1.38	3.88
United States	-0.10	-1.31	1.45	2.00
Overall	0.19	-1.32	1.45	3.85

Table 1: Average and standard deviation of annual inflation rates for 11 countries, 1880 - 1913

2. The lack of inflation between 1880 and 1913 was achieved by countries experiencing deflation over the first part of the period and inflation over the remainder. The average rates of inflation in the periods 1880 to 1895 and 1895 to 1913 are given in the third and fourth columns, respectively, of Table 1, and the behaviour of the price levels over time is plotted in Figures 2 and 3. Over the period 1880 to 1895, all 11 countries experienced deflation averaging between 0.53 percent (France) and 2.35 percent (United Kingdom). Over the period 1895 to 1913, all 11 countries experienced inflation averaging between 0.48 percent (Denmark) and 2.15 percent (Canada).[16]

   The change from deflation to inflation appears to have been due to an increase in the rate of gold production, as shown in Figure 4. The rate of increase in the world stock of gold was less than 2 percent per year between 1880 and 1892. However, the rate of change of the world gold stock increased after 1892, and, except for 1912, was consistently above 3 percent per year from 1894 to 1913. The change in the rate of

[15] All inflation rates are computed as $100 * (ln(P_t) - ln(P_0))/t)$.

[16] Although 1895 is not the year in which the price index is the lowest for all countries, I choose it as the breakpoint because it is the year with the minimum price level for the majority of countries considered.

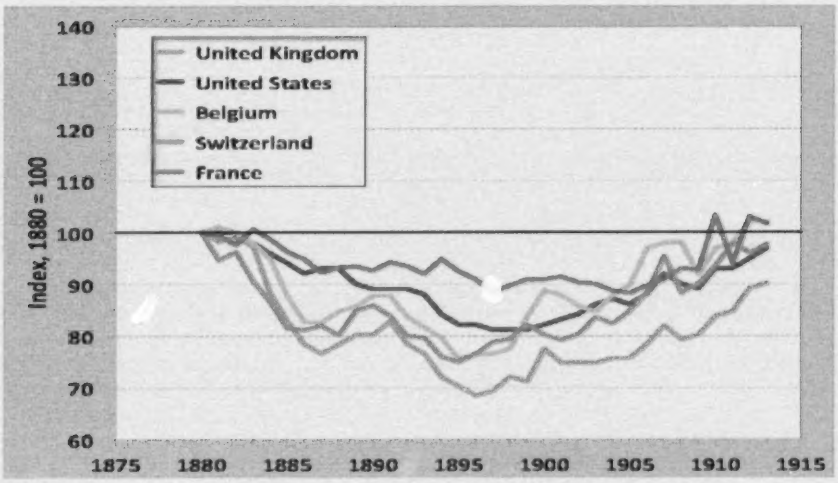

Figure 2: Price levels in selected countries, 1880 -1913

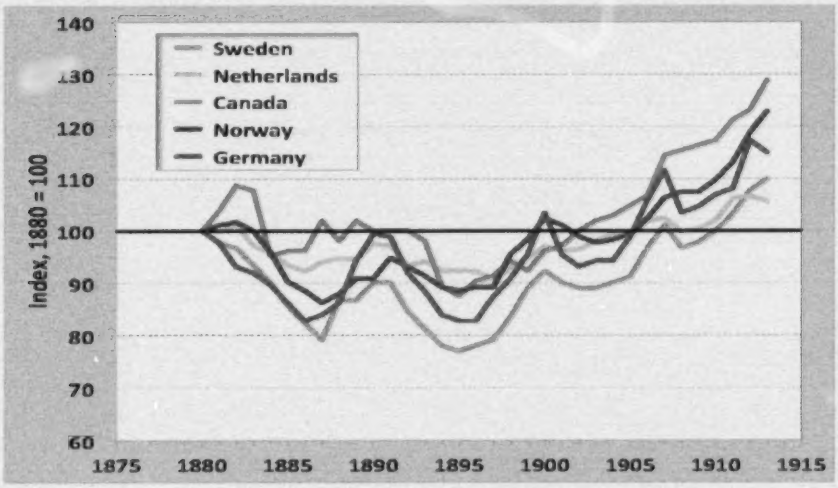

Figure 3: Price levels in selected countries, 1880 -1913

gold production was due to the discovery of gold in South Africa (the Rand) in 1886 and the invention of the cyanide process for smelting gold in the late 1880s.

The change in the rate of gold production and the change in the rate of inflation before and after 1895 accord reasonably well with the quantity theory of money,

$$\Delta P = \Delta M - \Delta Y + \Delta V, \tag{2}$$

which states that the rate of inflation, ΔP, equals the rate of money growth, ΔM, less

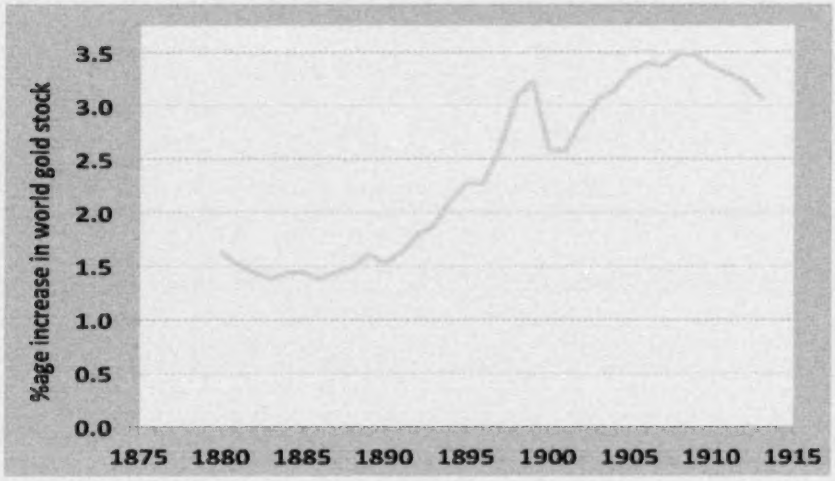

Figure 4: Percentage change in the world gold stock, 1880 -1913

the rate of real output growth, ΔY, plus the rate of change of velocity, ΔV. The average rate of increase of the world gold stock between 1880 and 1895 was approximately 1.5 percent per year. From 1895 to 1913, it was approximately 2.9 percent per year. If the change in the world stock of gold is interpreted as ΔM in Equation (2), then the quantity theory predicts that inflation should have increased by about 1.4 percent per year in the latter period over the earlier. This is a bit below the difference in the overall inflation rates in the last line of Table 1, but it must be remembered that this crude calculation assumes that there was no change in the rate of output growth between the two periods.

3. Overall, the price levels of the 11 sample countries moved closely together. The average of the correlations is 0.70 and the median is 0.76. However, a country-by-country examination of the correlations given in Table 2 shows that price-level movements were closer for some countries than for others.

   In Table 2, I have separated countries into blocks with price-level correlations of 0.8 or greater. Three blocks emerge: Block 1: the United Kingdom, the United States, and Denmark; Block 2: Belgium and Switzerland; Block 3: Sweden, the Netherlands, Canada, Norway and Germany. France appears to be different from the other countries, so I keep it by itself. Price levels in Blocks 1 and 2 appear highly correlated with each other. This is shown in Figure 2.[17] The price levels in these countries fall until approximately 1895 and then rise until 1914, but only Belgium's price level is higher at the end of the period than it was in 1880.

[17] I have omitted Denmark from Figure 2 because the figure was getting crowded.

	United Kingdom	United States	Denmark	France	Belgium	Switzer-land	Sweden	Nether-lands	Canada	Norway	Germany
United Kingdom	x	0.92	0.93	0.78	0.83	0.82	0.67	0.57	0.51	0.45	0.39
United States		x	0.83	0.77	0.76	0.77	0.57	0.51	0.54	0.34	0.28
Denmark			x	0.70	0.80	0.75	0.64	0.56	0.46	0.45	0.38
France				x	0.64	0.63	0.53	0.43	0.47	0.45	0.32
Belgium					x	0.92	0.93	0.87	0.79	0.79	0.76
Switzerland						x	0.90	0.87	0.81	0.76	0.75
Sweden							x	0.95	0.87	0.93	0.92
Netherlands								x	0.90	0.91	0.90
Canada									x	0.88	0.84
Norway										x	0.91
Germany											x

Table 2: Price level correlations for selected countries, 1880 -1913

	United Kingdom	United States	Denmark	France	Belgium	Switzer-land	Sweden	Nether-lands	Canada	Norway	Germany
United Kingdom	x	0.58	0.53	0.32	0.65	0.50	0.74	0.57	0.56	0.81	0.72
United States		x	0.21	0.30	0.50	0.46	0.46	0.45	0.53	0.42	0.28
Denmark			x	0.24	0.33	0.05	0.36	0.30	0.29	0.59	0.31
France				x	0.37	-0.09	0.19	-0.12	-0.10	0.30	0.20
Belgium					x	0.37	0.72	0.58	0.23	0.69	0.65
Switzerland						x	0.54	0.61	0.45	0.41	0.58
Sweden							x	0.66	0.20	0.75	0.75
Netherlands								x	0.28	0.47	0.55
Canada									x	0.42	0.27
Norway										x	0.60
Germany											x

Table 3: Inflation rate correlations for selected countries, 1880 -1913

4. There was a large amount of year-to-year fluctuation in annual inflation rates. This is shown in the fifth column of Table 1 and in Figures 5 and 6. The sample standard deviations are between 2 and 5 percent.

5. Annual inflation rates among countries were not highly correlated, as shown in Table 3. The average of the correlations in the table is 0.43 and the median is 0.45. These are much lower than the average and median for the price levels of these countries. The table shows that inflation rates of the other countries in the sample are mostly highly correlated with British inflation. The table also shows that France once again appears to be an outlier. It has the lowest correlations with other countries in the sample. Further, in three cases (the Netherlands, Switzerland and Canada), France's

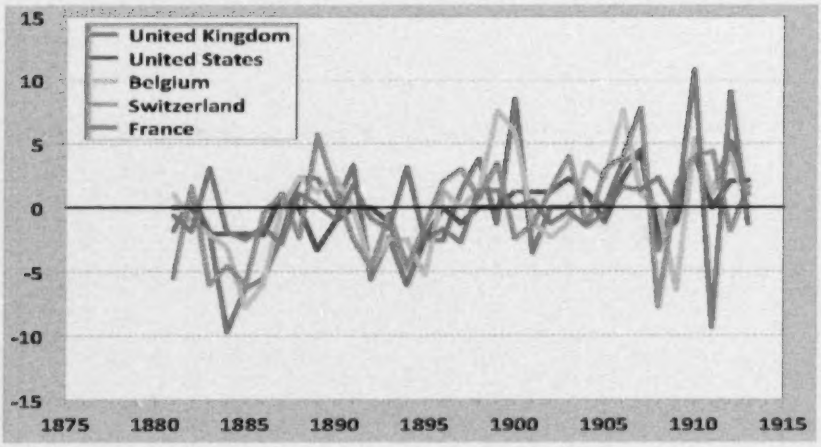

Figure 5: Inflation rates for selected countries, 1880 -1913

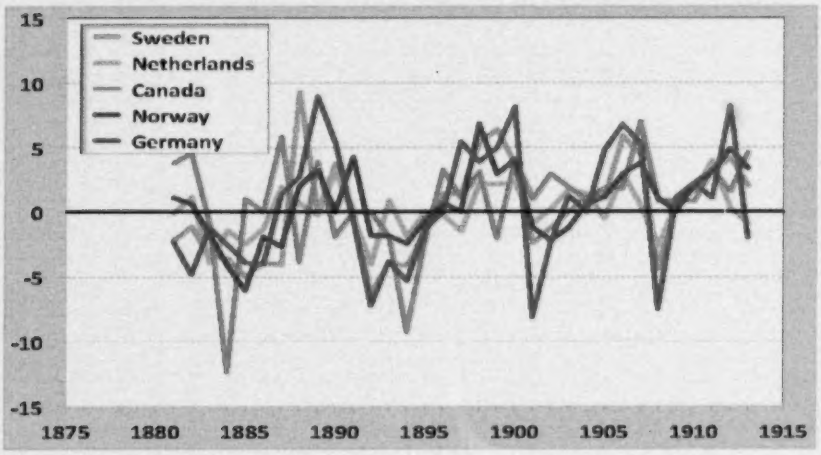

Figure 6: Inflation rates for selected countries, 1880 -1913

inflation rate is slightly negatively correlated with the inflation rates in those countries, although the correlations are so small as to be considered essentially zero.

Extrapolating from the price-level experience under the gold standard, I have three conjectures about the behaviour of country price levels under the Bitcoin standard.

Conjecture 1: In the long run, inflation would not be zero. Instead, there would be moderate deflation that would increase over time until reaching a rate of deflation equal to the negative of the rate of growth of world output around 2026.

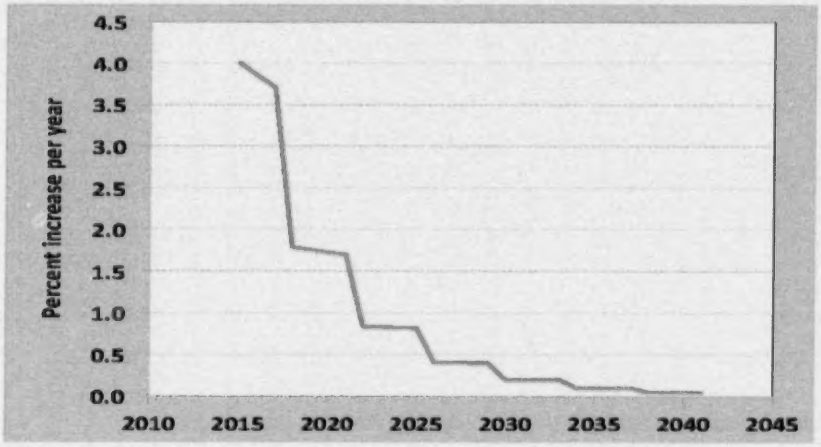

Figure 7: Percentage growth rates of Bitcoin, 2015 - 2040

Changes in the world stock of Bitcoin are set according to the algorithm that determines how many new Bitcoins "miners" receive for verifying transactions. The percentage increase in the world stock of Bitcoins in each year from 2015 until 2040 is shown in Figure 7.[18] The figure shows that the rate of growth of Bitcoin is declining every year and that beginning around 2018 the growth rate is less than 2 percent, beginning around 2022 the rate of growth falls to less than 1 percent per year and beginning around 2026 the growth rate falls to less than 1/2 percent per year.[19]

I assume that the rate of growth of the money supply is tied to the rate of growth of world Bitcoin, so that ΔM is close to the rate of Bitcoin growth and is declining over time. Substituting into (2) and assuming that world output growth (ΔY) is at a rate of between 2 and 3 percent per year and that velocity growth (ΔV) is close to zero, there will be deflation beginning in 2018 and the rate of deflation will increase over time until it is in the range of 2 and 3 percent per year beginning around 2026.

Conjecture 2: There would not be periods of deflation followed by periods of inflation as was the case under the gold standard.

[18]The timing is approximate because I have plotted the percentage changes at 4-year time intervals. In addition, percent change is approximate because Bitcoin can be lost if the private keys associated with them are lost or destroyed through hard drive crashes or losses of paper wallets. I am indebted to Hanna Halaburda for these examples. Nonetheless, the deviations of actual growth rates from those in my figure will be extremely small.

[19]The total quantity of Bitcoin is capped at 21 million by the algorithm for creating Bitcoin. That cap will be hit in 2140.

As argued above, the change from general deflation to general inflation under the gold standard was the result of a marked increase in the rate of gold production due to gold discoveries and technological improvements in the process for smelting gold. Such marked changes in the rate of change of the stock of the anchor would not occur under the Bitcoin standard: its rate of change is determined by the fixed algorithm governing the rate at which miners can add transactions to the blockchain. It is not subject to changes in, or to incentives to change, the rate of production to which a commodity anchor is subject.

Corollary: Suppose that real interest rates are also somewhere around 3 to 4 percent. Then the Fisher equation implies that nominal interest rates on safe assets would be very close to zero and could be negative if real output growth were high enough. In other words, if real interest rates are in this range, then under the Bitcoin standard countries would have nominal interest rates close to those in the major developed countries today and would be close to the Friedman rule.

Conjecture 3: Price levels of the various countries would be highly, but not perfectly, correlated, much as they were under the gold standard.

My reasoning is that under the Bitcoin standard, just as under the gold standard, the money supplies of different countries would not necessarily move together, although the more tightly a group of countries are linked in terms of trade and finance, the more closely their money supplies would be linked.

Exchange Rates

A major reason that countries adopted the gold standard was to achieve stability of their exchange rates against those of other countries that also adopted the gold standard. The mechanism through which such stability was to be achieved was gold arbitrage. However, because there were costs associated with gold arbitrage, the exchange rates between the fiduciary currencies of different countries were not fixed but were restricted to a range around their par values known as the "gold points."[20] Because gold arbitrage was less costly the closer countries were in terms of geography and financial integration, the narrower should have been the range of fluctuations in exchange rates of their currencies.

In Figure 8, I plot the premium on the U.S. dollar, in percent of par, versus the CAD, the U.K. pound sterling and the French franc. The figure shows that the gold standard achieved stability of exchange rates. On average, exchange rates were close to their par values, and fluctuations were generally quite small. The U.S. dollar averaged a 0.025 percent premium over the CAD and a 0.012 percent premium over the franc. It averaged a 0.079 percent discount against the pound sterling. Further, the standard deviation of premia were only 0.104 percentage points, 0.234 percentage points, and 0.353 percentage points for the CAD, pound sterling and franc, respectively. Discounts and premia were always less than one percent for the U.S. dollar - pound sterling and U.S. dollar - franc and were less than

[20]Par value is the ratio of the quantity of pure gold in which the currencies of different countries were defined. For example, the U.S. dollar and the CAD were defined to equal 1.50463 grams of pure gold. Thus, their par value was 1. The pound sterling was defined to equal 7.322381 grams of pure gold, so that the ratio of the U.S. dollar and the CAD to the pound sterling was 4.86656331. Similarly, the French franc was defined to be equal to 0.290322581 grams of pure gold, so that the ratio of the franc to the U.S. dollar and CAD was 0.1929581. How gold points were determined is explained in Appendix I.

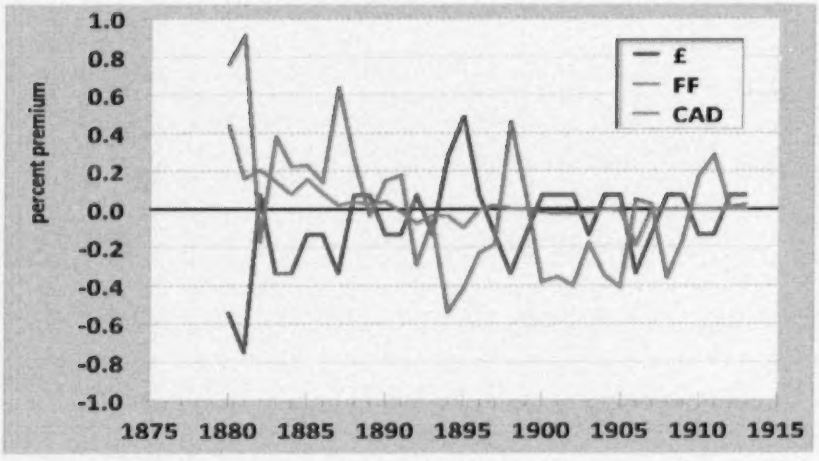

Figure 8: Percentage premia of selected currencies against the dollar, 1880 -1913

one-half percent in the vast majority of years. In terms of the U.S. dollar - CAD, in only one year was the premium on the U.S. dollar greater than one-quarter of a percent.

Figure 8 also shows that the range of exchange rate fluctuations was directly related to the costs of undertaking gold arbitrage. The range of exchange rate fluctuations was the smallest for the U.S. dollar and the CAD. The cost of gold arbitrage between the United States and Canada was very small. The countries were close together geographically, so the time and freight costs of shipping gold were quite small. Further, it is likely that many Canadian dealers in gold maintained accounts with banks in New York. The range was next smallest for the U.S. dollar and the pound sterling. Although separated by the Atlantic Ocean, which would have meant that physically transferring gold would have taken time and involved shipping costs, the financial markets of the United States and the United Kingdom were closely connected. Further, London was the predominant financial market at the time. The range was highest for the U.S. dollar and the franc. The costs of shipping gold from New York to Paris were at least as high as shipping it from New York to London, and Paris was a much less developed financial market. In addition, the trade connections between the United States and France were not as strong as those between the United States and the United Kingdom.

Conjecture: Under the Bitcoin standard, the exchange rates among the fiduciary currencies of various countries would be fixed at par, because the cost of Bitcoin arbitrage is essentially zero.

Real Output Growth

The time series of real GDP for Canada, France, the Netherlands, Norway, the United Kingdom and the United States are plotted in Figure 9 and summarized in Table 4. The

figure and table show three points:

1. Real output growth was strong in some countries and weak in some others during the classical gold standard period. Canada and the United States experienced strong growth. Real GDP grew at an annual rate of 4.41 percent in Canada and 3.45 percent in the United States during that time. However, real output growth was much slower in the four European countries, averaging between 2.28 percent in the Netherlands and a meager 1.28 percent in France.

2. During the period 1880 to 1895, when there was generally deflation in countries on the gold standard, all six countries experienced real growth. Once again, growth was stronger in Canada and the United States than it was in the four European countries.

3. In Canada, the Netherlands, Norway and the United Kingdom, growth rates were markedly higher in the period 1896 to 1913 when there was general inflation than in the earlier period of general deflation. The United States and France, however, had lower average annual real output growth in the inflation period than in the deflation period.

Conjecture: Average real growth among countries would be much like average growth among countries today. For example, the International Monetary Fund estimates that world real GDP grew at an average rate of 3.5 percent over the period 1969 to 2014. Further, real output growth would vary widely across countries. Figure 9 and Table 4 show that this was definitely the case under the gold standard. The recent experience of the Eurozone countries shows that this can also be the case for countries on the same monetary standard today. I see no reason why that would not continue to be the case under the Bitcoin standard.

This conjecture is only partly based on the evidence from the gold standard period, however. It is based more on the fact that real output growth depends on the growth in human and physical capital and on the growth in total factor productivity. In my opinion, there is no reason to think that the growth rates of these factors would be much affected by the adoption of the Bitcoin standard.

Some might be concerned, using Phillips curve reasoning, that real growth would be extremely slow under the Bitcoin standard because of the deflation that would occur under it. The evidence from countries on the gold standard shows that this concern is to some extent unwarranted.

Financial Crises

To determine the likelihood of financial crises under the gold standard, I use the data on banking crises from Reinhart and Rogoff (2009, Table A.3.1). The data show that financial crises were quite likely. At least one gold standard country had a banking crisis in about a third of the years during the period 1880 to 1913. According to the Reinhart and Rogoff (2009) data, there were banking crises in 1880, 1882, 1885, 1889, 1890, 1891, 1897, 1898, 1901 and 1907 in one or more countries that were on the gold standard. In most cases, the

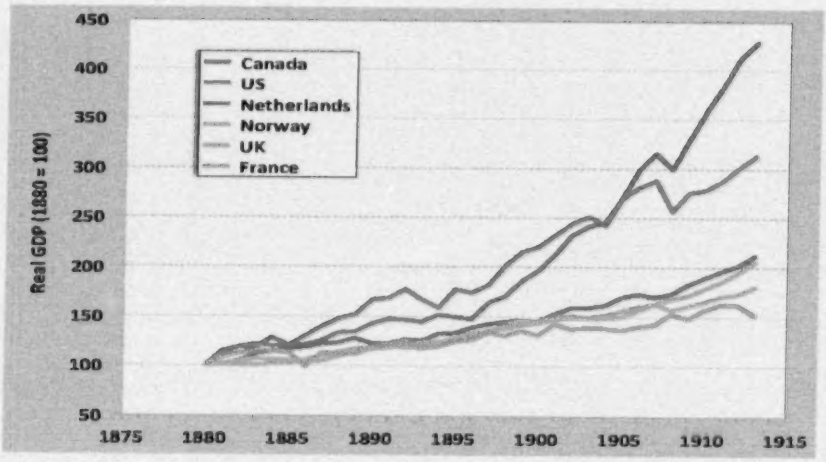

Figure 9: Real GDP in Selected Countries, 1880 -1913

	Average		
Country	1880 - 1913	1880 - 1895	1895 - 1913
Canada	4.41	2.67	5.86
France	1.28	1.48	1.11
Netherlands	2.28	1.91	2.58
Norway	2.18	1.55	2.72
United Kingdom	1.79	1.64	1.93
United States	3.45	3.80	3.16

Table 4: Average annual real output growth for 6 Countries, 1880 - 1913

banking crisis was only in a single country. However, in 1891, 1892, 1897 and 1907 more than one country experienced a banking crisis.[21]

Utilizing their data, I present in Table 5 a list of 14 countries that had a financial crisis during the period when they were on the gold standard. The table also shows the number of years that each was on the gold standard between 1880 and 1913, and the number of financial crises in each.[22] The table shows that six countries had one crisis, four countries had two, and four had three. Their data also show that there were a number of countries that were on the gold standard but did not have a financial crisis. More specifically, there were six countries (Belgium, Canada, Colombia, Indonesia, Switzerland and Turkey) that were on the gold standard during the entire 34 years but did not have a financial crisis, and

[21]The Reinhart and Rogoff (2009) table lists eight other countries that experienced banking crises between 1880 and 1913. I have been unable to determine whether those countries were on the gold standard at the time the crises occurred. Therefore, these crises are not included in my calculations.

[22]My dating of when countries were on the gold standard is from Meissner (2005, Table 1).

another 11 that were on the gold standard for part of the period but did not have a financial crisis.[23]

	Years on gold standard	Number of banking crises		Years on gold standard	Number of banking crises
Australia	34	1	Mexico	9	2
Denmark	34	2	Netherlands	34	1
Finland	34	1	Norway	34	1
France	34	3	Portugal	34	
Germany	34	3	Sweden	34	2
Italy	30	3	United Kingdom	34	1
Japan	17	1	United States	34	3

Table 5: Number of banking crises in countries on the gold standard

Conjecture: There would be financial crises under the Bitcoin standard. Financial crises have occurred in all financial systems, whether commodity-backed or fiat, in which financial institutions have demand liabilities that are not matched by assets with the same maturity. The Bitcoin standard would exhibit such maturity mismatches. Of course, such crises can be mitigated to some extent by government deposit insurance, which under the Bitcoin standard could be provided by fiduciary currencies issued by central banks. However, deposit insurance provision would be limited, because the ability of governments to issue fiduciary currency is limited under the Bitcoin standard. And, historically, deposit insurance has not prevented financial crises.

5 Would the Bitcoin Standard be Stable?

Canada permanently left the gold standard in 1929; Britain and Germany in 1931; the United States in 1933; and France in 1936. This experience with the gold standard raises a question about the Bitcoin standard: If it were to come into being, would it last for a substantial period of time, or would it be replaced by some other monetary system?

In my opinion, whether the Bitcoin standard would last a substantial period of time depends on how the Bitcoin standard came into existence. The first case is that in which the Bitcoin standard would come into being gradually over time, which is the way the gold standard came into being. That is, the Bitcoin standard came into being because the number of merchants accepting Bitcoin gradually increased over time and because using Bitcoin became increasingly more convenient as the time to verify and complete transactions became even shorter to the point where no one used the old media of exchange.

My conjecture for this case is that the Bitcoin standard would not last long. There would be a major cyclical downturn or financial crisis that would lead to political pressure and

[23] I have omitted Argentina, Chile and Uruguay from the discussion, since I am not able to determine whether their financial crises occurred during the period when they were on the gold standard or during the period when they were off it.

demands for central banks to remove the "Bitcoin fetters" that prevent them from inflating to stimulate the economy or from providing large amounts of assistance to financial institutions in trouble.[24] Central banks or governments would eventually yield to this pressure and break the ties between their currencies and Bitcoin, just as central banks and governments did when they went off the gold standard before and during the Great Depression. In other words, the currencies of central banks or governments would become fiat currencies rather than fiduciary currencies.

In this case, I expect that Bitcoin would continue to play a role as a medium of exchange, since it had been the anchor of the monetary system. It would continue to have a role as a means of payment for exactly the same reasons that it has a role as a medium of exchange today. One reason is that it would eliminate the transactions costs of switching between central bank currencies when making transactions in different countries. Also, because there could now be fluctuations in the exchange rates between central bank currencies, Bitcoin would provide a means of hedging against these fluctuations. The allure of reaping these benefits was one of the major reasons European countries gave up their individual currencies and adopted the euro.

The second case is that in which countries had been on fiat monetary standards similar to the ones in existence today, but for some reason their fiat currencies are no longer valued, have gone out of existence and have been replaced by the Bitcoin standard. Further, there is no possibility of a return to a fiat standard. One of the major reasons that this could occur is that countries have been following bad monetary policies that have led to high rates of inflation.

My conjecture for this case is that the Bitcoin standard still might not last long. One possibility is that the economy could switch from an equilibrium in which Bitcoin is valued to an equilibrium in which it is not. The possibility of multiple equilibria occurs with any monetary system based on an object, such as Bitcoin, that is intrinsically useless. In any such monetary system, there are two equilibria. In one equilibrium the money is valued; in the other it is not. Whether an intrinsically useless medium of exchange is valued depends upon whether agents expect it will be accepted in transactions in the future. If at any point people expect that Bitcoin will not be accepted in future transactions, it will lose its value at that time.

In the case of Bitcoin, the switch to no longer valuing Bitcoin could occur for several reasons. One is fear of an attack on the blockchain by a group of dishonest miners. Such an attack would eliminate the decentralized nature of the blockchain ledger and give control of Bitcoin to a single entity. Such control would allow this entity to determine which transactions are permitted and give it the power to roll back transactions. Eyal and Sirer (2013) argue that, at a minimum, 2/3 of miners and more likely 3/4 of miners, have to be honest in order for such an attack to not be feasible.[25] A second reason is extrinsic uncertainty ("sunspots").

Nonetheless, I think the probability that it would happen is virtually zero. For an intrinsically useless medium of exchange to be valueless, it must happen that no agent

[24] According to Keynes (1932, 288) when Britain went off the gold standard in 1931, "There are few Englishmen who do not rejoice at the breaking of our gold fetters."

[25] Eyal and Sirer (2013) describe the strategy for one such attack called "Selfish-Mine."

expects it to be accepted by any other agent either now or in the future. As long as there is some agent, say a government willing to accept the medium of exchange for taxes, that other agents believe will always accept the medium of exchange, then it will always have value.

A more likely possibility in this case is that the Bitcoin standard would be replaced by a different cryptocurrency-based standard. There are over 700 different cryptocurrencies in existence today. People could decide to switch to one of them that has better properties; for example, stable prices or very moderate inflation. However, as Eyal and Sirer (2013) point out, the possibility for an attack exists for any currency that has a decentralized ledger similar to Bitcoin's blockchain.

Another possibility is there could be political pressure demanding that central banks or governments offer an intrinsically useful fiduciary currency to compete with Bitcoin. By an intrinsically useful fiduciary currency I mean a currency backed by some commodity or basket of commodities.[26] If central banks or governments could credibly commit to redeem this currency on demand, and if they were willing to give up their own monetary units and adopt a uniform one, then this might be widely accepted as a medium of exchange and might drive out Bitcoin to a great extent. My reason for including the elimination of individual country monetary units is to make clearing simpler and to facilitate the use of the currency across country lines. In other words, the Bitcoin standard might not be stable because a euro-like commodity-backed money could provide the benefits of the Bitcoin standard without its inherent stability issues.

6 Conclusions

A Bitcoin standard would have two major benefits over current fiat money standards. One is that there would be greater price-level predictability due to the known, deterministic rate at which new Bitcoins are created. A second is that the resources currently devoted to hedging against fluctuations in exchange rates would be freed up to be used in more productive ways.

Nonetheless, in my opinion it is unlikely that the Bitcoin standard will come into existence, because governments and central banks will take actions to prevent it. They will do so for two reasons. One is to protect the seigniorage revenues that they obtain from the ability to almost costlessly create money. The second is to retain the ability to implement interest policies to affect their domestic economies. Governments would lose the ability to do either or both of these under the Bitcoin standard.

Even if the Bitcoin standard were to come into existence, it is my opinion that it would not last long. The payments world is changing so rapidly that there will be a technological innovation that provides a potential medium of exchange with the same or greater benefits of Bitcoin or with lower costs. Such an innovation could come either from the private sector or from the government.

[26]This raises the question of whether this backing should be gold or something else. As Bordo (1984, 27) points out, "an important defect of the gold standard" was that it based "a nation's money supply on one commodity subject to changing demand and supply conditions." It was because of this defect that in the 1920s through the 1940s there were numerous suggested alternatives to the gold standard. Among these alternatives were bimetallism, symmetallism and the generalized commodity reserve currency. For references to these proposed schemes and a discussion of how they could work, see Weber (1980).

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Appendix I: The Gold Standard

The gold standard did not come about as a joint agreement among countries. Rather, it came about over a period of time as one country after another chose to abandon its silver or bimetallic standard in favour of the gold standard. The reason for the choice of gold, rather than some other commodity or basket of commodities, as the "anchor" was due "largely to Britain's early steadfast adherence to gold and its commercial and financial significance" (Meissner, 2005, 401).

The history of the gold standard was marked by changes over time in the number of countries that adopted it.[27] The origins of the gold standard are usually dated to England in 1717 "when Sir Isaac Newton, then Master of the Mint, set too high a silver price for the gold guinea" (Eichengreen and Flandreau, 1997, 4). However, England did not legally adopt gold as the sole backing for its currency until 1821 with the passage of an act on 2 July 1819 that required the Bank of England to redeem its notes in gold.

Canada adopted a gold-backed currency on 14 June 1853 with the passage of the "Act to regulate the Currency," which set the value of the Canadian dollar and the Canadian pound in terms of grains of standard gold. Germany went off of silver and established the gold-based mark in 1872 after receiving a large quantity as reparations from France. France and the other countries of the Latin Monetary Union went off a bimetallic standard for their currencies and adopted gold in 1878.[28] The United States effectively adopted the gold standard on 1 January 1879 with the resumption of the convertibility of U.S. notes into gold, although the gold standard was not officially adopted until the passage of the Gold Standard Act in 1900.

Because the gold standard was so prevalent in the late nineteenth and early twentieth centuries, the period 1880 to 1913 is sometimes referred to as the "classical gold standard" period. According to Bloomfield (1959, 14-15), "By the end of the [nineteenth] century nearly all the leading countries had linked their currencies to gold in one form or another; and many of the smaller Asiatic and Latin American countries did so in the late 1890's and early 1900's." Countries also changed whether or not they were on the gold standard. Again, according to Bloomfield (1959, 15),

> A number of countries dropped out of the "club" during the course of the period, such as Argentina (1885), Portugal (1890), Italy (1891), Chile (1898), Bulgaria (1899), and Mexico (1910); but Argentina, Italy, and Bulgaria returned to gold ... in 1900, 1902, 1906.

Details

Under the gold standard, each country had its own monetary unit. In the United States it was the dollar; in the United Kingdom, the pound; in Canada, initially both the dollar and the pound although eventually it became only the dollar. This monetary unit was defined

[27] This historical discussion is based on Bloomfield (1959), Frieden (1992), Eichengreen (1992), and Eichengreen and Flandreau (1997).

[28] A bimetallic standard is a monetary system based on both gold and silver. See Redish (2000) for a discussion of bimetallism and an argument as to why bimetallic standards evolved to the gold standard.

as consisting of a given number of troy grains or ounces of gold of standard fineness.[29] For example, when Canada went on the gold standard in 1853, the Canadian pound was defined to have 101.321 grains of gold and the Canadian dollar as having one-fourth of that, so that there were 20.67 Canadian dollars per troy ounce of gold. The ratio of the monetary unit to the quantity of gold was known as the "mint price." There were no restrictions on the importing or exporting of gold under the gold standard.

Each country had its own mint that would produce gold coins of various denominations. These mints would accept bullion in unlimited amounts and exchange coins for bullion. That bullion could be brought in unlimited amounts was known as "free coinage." However, "free" did not mean that there might not be a charge for minting. A mint might charge for the cost of coinage (brassage). In addition, it might charge a tax (seigniorage). The result was that persons bringing bullion to a mint might receive less than that weight in coinage in return.

Under the gold standard, central banks or government treasuries issued fiduciary currencies. These were (paper) currencies that were not 100 percent backed by gold, but were tied to gold in some manner. For example, in the United Kingdom, the Bank of England issued bank notes that had to be redeemed in a specific amount of gold on demand. In the United States, the Treasury issued U.S. notes, and, later, the Federal Reserve System issued Federal Reserve notes. Both were redeemable in gold on demand. In Canada, the Treasury issued Dominion notes, which were also redeemable in gold.

Among the countries that adopted the gold standard, there were differences in the manner in which their fiduciary currencies were tied to gold. One difference was the nature of the legal convertibility of the fiduciary currency. In the three countries mentioned above and in most other countries, the issuer of the fiduciary currency was required to redeem it in gold on demand. This was not the case in all countries that adopted the gold standard, however. Some – France is an example – made the legal convertibility of the fiduciary currency the option of the monetary authority.[30]

A second difference in the nature of how countries tied their fiduciary currencies to gold was the required gold backing of the fiduciary currency. Some fiduciary currencies were fractionally backed. That is, the central bank or treasury issuing the currency had to hold gold in a given proportion to the currency issued. For example, in the United States, the Federal Reserve System had to back Federal Reserve notes 40 percent with gold. Other countries required their fiduciary currencies to be 100 percent backed above some amount with fractional or no backing of the currencies up to this amount. In Britain, the "Bank Charter Act 1844" (Peel's Act) permitted the Bank of England to issue notes up to a specific amount with no gold backing. However, note issuance above that amount had to be 100 percent backed by gold. Canada first authorized the issuance of fiduciary currency by the Dominion Notes Act passed in 1868. Under the terms of this Act, the initial issuance of Dominion Notes was capped at CAD 8 million. The first CAD 5 million had to be 20 percent backed by gold; the next CAD 3 million, 25 percent backed by gold. Canada changed the maximum issuance and required backing for Dominion notes over time. By 1913, the first

[29]The difference between a troy ounce and a avoirdupois ounce is that a troy ounce is 480 grains, whereas the avoirdupois ounce is 437-1/2 grains. The standard fineness of gold is $\frac{22}{24} = 0.9167$ karats.

[30]Bloomfield (1959) refers to a country imposing legal convertibility on demand as being on the "full" gold standard. He refers to a country as having adopted a "limping" gold standard when convertibility is at the option of the issuer.

CAD 30 million had to be 25 percent backed by gold; issuance over CAD 30 million had to be fully backed by gold.

Reasons for Adoption

With a convertible fiduciary currency some of an economy's resources are idle, because they must be stored as reserves. One advantage of an inconvertible fiduciary (fiat) currency is that reserves are not needed, and so these resources are available for other uses. The presumption under a fiat currency regime is that these other uses are productive. However, it could be the case that the resources are idle because they are being used for non-productive uses, such as hedging against possible inflation.

Despite this possible advantage of a fiat monetary standard, there was a major concern that contributed to the adoption of the gold standard: under a fiat monetary standard, monetary authorities would inevitably end up continually depreciating a country's money. Linking a country's money supply to a commodity such as gold would prevent this from occurring. In this way, gold would be an "anchor" to the monetary system. Requiring convertibility into gold would limit the issuance of fiduciary currency and help achieve the goal of price-level stability. According to Bordo (1984, 23):

> A stable price level in the long run that an automatically operated gold standard produced, in line with the commodity theory of money, was invariably contrasted to the evils of inconvertible fiduciary money. At the hands of even well-meaning policy-makers the latter would inevitably lead to depreciation of the value of money.

The reasoning is as follows.[31] Assume a closed economy and that the quantity of money in it is a function of its monetary gold stock:

$$M = 1/\lambda G, \tag{3}$$

where M is the money stock, G is the monetary gold stock, and following Barro (1979) λ is a parameter of the gold backing of the monetary authority's fiduciary currency. Among other things, λ will depend upon the quantity of gold that the economy's monetary authority is required to hold to back its fiduciary currency issues. Then substituting (3) into the quantity theory, equation (2), yields

$$\Delta P = 1/\lambda \Delta G - \Delta Y + \Delta V, \tag{4}$$

where Δ denotes a rate of growth.

However, (4) does not yield the result of stable prices under the gold standard. According to (4), if a country's stock of monetary gold is increasing faster than its rate of growth of real output, the price level would be continually increasing. The opposite would be the case if its stock of monetary gold were increasing less rapidly than its rate of growth of real output.

The stable price-level result follows from the fact that the production of new gold takes real resources and has positive and increasing marginal costs of production. Therefore, the nominal cost of production of new gold is increasing in P. Let P_g be the rate at which the

[31] I derive this discussion from the analysis in Barro (1979).

monetary authority will buy or sell its fiduciary currency for gold. Then, given that gold producers are revenue-maximizing, the rate of production of new gold will vary inversely with P/P_g. Thus, if gold production outstrips output and inflation results, the fact that gold production is now more costly would act to reduce the rate of gold production. That is, ΔG would fall, which according to (4) would reduce the rate of inflation. The opposite will occur if gold production is less than output growth. Of course, these effects would not occur instantaneously.

It can be argued that this is what happened in the late 1880s and early 1890s. The general deflation, shown in Figures 2 and 3 in the main text, would have provided incentives to increase gold exploration and production, which did occur. The subsequent inflation was the correction to achieve the price-level stability that the gold standard was supposed to provide.

The "Price-Specie Flow" Mechanism

If other countries also adopt the gold standard, then not only would they all avoid inflation, but their price levels also would be linked through a mechanism known as the "price-specie flow" mechanism. In fact, the price levels would be more than simply linked. The price-specie flow mechanism argues that price levels would be equalized across the countries that have adopted the gold standard.

Two basic ideas underlie the price-specie flow mechanism. The first idea is gold arbitrage: gold will flow from countries where it has a low degree of purchasing power (where the price level is high) to the countries where it has a high degree of purchasing power (the price level is low). The second idea is one stated above: under the gold standard, the money supply in a country depends on the quantity of gold in that country. Thus, following the quantity theory of money, the price level in a country increases when it receives gold and declines when it loses gold.

To see how the price-specie flow mechanism is supposed to work, let there be two countries, call them Country A and Country B. Let P_j be the price level in country j (monetary units/good) and X_j be the mint price in country j (monetary units/ounce of gold), $j = A, B$. Consider an agent who has one ounce of gold. This agent faces the question of where to buy commodities. If the agent takes the ounce of gold to Country A, the ounce of gold is worth X_A units of Country A currency, which buys $\frac{X_A}{P_A}$ units of goods. If the agent takes the ounce of gold to Country B, the ounce of gold buys $\frac{X_B}{P_B}$ units of goods.

If $\frac{X_A}{P_A} > \frac{X_B}{P_B}$, then the ounce of gold buys more goods in Country A than in Country B. According to the price-specie flow mechanism, the result is that gold flows from Country B to Country A. Agents want to buy goods where they are the cheapest. This is the gold arbitrage. The flow of gold into Country A increases its money supply, and the flow of gold out of Country B decreases its money supply. And because the price level in a country is related to its money supply, the price level will increase in Country A and decrease in Country B. The gold flow, the arbitrage, continues until $P_A = P_B$.

Achieving price-level stability was a major reason why a country might adopt a commodity standard such as the gold standard. Given that other countries, especially countries such as Britain that were important in international trade and finance, were on the gold standard, there was another reason for a country to choose the gold standard: it would serve

to maintain balance of payments equilibrium among the countries that adopted it.

To see how, suppose that Country A was running a balance of payments surplus. Then, Country A would be experiencing a gold inflow. This gold inflow would increase its money supply and increase its price level. The increase in the prices of its goods would tend to make them less attractive to foreigners and thereby reduce its balance of payments surplus. The reverse mechanism would work if a country were running a balance of payments deficit. Further, the adjustment would be automatic. The gold flows induced by the trade imbalances would lead to money supply changes, leading to price changes that would undo the trade imbalance.

The supposed automaticity of balance of payment adjustment under the gold standard would have had the added benefit of removing the incentive for countries to change the gold content of their fiduciary currencies; i.e., to devalue or revalue their currencies, in order to achieve balance of payments surpluses or overcome balance of payments deficits. Any short-term effects of such actions would have been undone by the changes in gold flows they effected.

Canada permanently left the gold standard in 1929; Britain and Germany in 1931; the United States in 1933; France in 1936. If the gold standard was so successful, why did it not last? Why did countries replace their gold-backed currencies with fiat currencies in the 1930s?

The answer, at least according to Eichengreen (1992): the political and economic changes that occurred or were accelerated by World War I. Two of the most important were:

1. Changes occurred in the composition of voters in countries on the gold standard, so that domestic priorities became more important and balance of payments concerns less important. The gold standard limited the ability of policy-makers to address issues such as unemployment and inflation, especially in times like the Great Depression.

2. The centre of international finance shifted away from London to New York. This was due in large part to the large gold reserves that the United States had accumulated during World War I.

"Rules of the Game"

If a country adopted the gold standard, its monetary authority was supposed to follow certain "rules of the game." The usual specification of the "rules" applied to how monetary authorities should adjust their bank rates in the face of persistent gold inflows or outflows. The "rule" was that a country's monetary authority was supposed to take actions to supplement the effects that the gold inflows or outflows were having on the country's balance of payments.

Consider the case of persistent gold inflows and assume that they were due to Country A running a balance of payments surplus. Without any central bank actions, the gold inflows would have served to raise prices in Country A, which would have had the effect of reducing the balance of payments surplus. Thus, as discussed above, there was automaticity of balance of payments adjustment under the gold standard.

The "rule" in this case was that the central bank in Country A was supposed to help the balance of payments adjustment by lowering its discount rates. Lowering the discount rate

would have two effects. First, it would reduce the incentive for gold to flow into Country A. Second, the lower interest rates would serve to stimulate the economy of Country A, which would increase its imports and reduce its balance of trade surplus. Monetary authorities were supposed to take the opposite action, increase bank rates, when experiencing persistent gold outflows.

Of course, the incentives for central banks to take these actions were asymmetric. The monetary authority of a country experiencing gold outflows had to raise interest rates. If it did not do so, it faced the possibility of running out of gold and being unable to redeem its fiduciary currency. The monetary authority of a country experiencing gold inflows faced no such pressure.

The question of whether countries moved their discount rates as the "rules of the game" required was explored extensively by Bloomfield (1959). Eichengreen and Flandreau (1997, 14) characterized his findings as:

> [he] found that pre-World War I central banks violated those ["rules of the game"] in the majority of years and countries he considered. Rather than draining liquidity from the market when their reserves declined (and augmenting it when they rose), they frequently did the opposite.

Bordo and Kydland (1995) have argued that there was a second part to "rules of the game" that applied to a country's commitment to redeem its fiduciary currency under the gold standard. When a country adopted the gold standard, it committed to redeem its fiduciary currency in gold at the established mint ratio. However, Bordo and Kydland (1995) argued that this commitment was state-contingent. A country was permitted to suspend redemption in the case of an exogenous emergency; e.g. war or if it were in danger of running out of gold during a financial crisis. Once the emergency was over, the country was committed to restore convertibility at pre-emergency parity.[32] An example of this state-contingent commitment is the actions of the Bank of England during the Napoleonic Wars. It suspended convertibility of its paper pound in 1797 and resumed convertibility at the old parity in 1821.

In the context of multiple countries on the gold standard, this commitment to restore convertibility at par after suspensions meant that countries were implicitly agreeing to maintain close to fixed exchange rates and to not engage in competitive devaluations after the emergency ended.

[32]This state-contingent commitment was similar to that which banks had with respect to redemption of their notes. They were permitted to suspend redemption in emergencies, such as bank panics which caused runs on their specie holdings, but they were to resume redemption once the panic was over. The difference between the commitment of banks and that of a country on the gold standard is that the banks' commitment was a legal requirement. Failure to resume meant that a bank would be put out of business. A country's commitment was more implicit.

Gold Points

Achieving price-level stability and having a mechanism that would work to automatically reduce balance of payments surpluses and deficits were two reasons for adopting the gold standard. However, according to the Macmillan Committee Report, which was written in 1931, "The primary objective of the international gold standard is to maintain a parity of foreign exchanges within narrow limits; this has the effect of securing a certain measure of correspondence in the levels of prices ruling all over the gold standard area."[33]

To see how the gold standard would work to "maintain parity foreign exchanges," which I interpret to mean relative constancy of exchange rates, let there be two countries on the gold standard, each of which issues its own fiduciary currency. For convenience, call these countries Canada and the United Kingdom. There is a spot market for the two currencies, and the spot exchange rate is $S = CAD/£$. Further, let X_{CA} be the mint price of the Canadian dollar and X_{UK} be the mint price of the U.K. pound. Recall that mint prices are in monetary units/ounce gold.

Consider the question of when Canadian citizens should import gold from the United Kingdom. Canadians could take 1 CAD to the spot market and get $\frac{1}{S}$ pounds. They could then take these pounds to the Bank of England and get $\frac{1}{SX_{UK}}$ ounces of gold. Then, they could ship the gold across the Atlantic Ocean, take it to the Canadian Treasury, and get $\frac{X_{CA}}{SX_{UK}}$ Canadian dollars. The alternative to using the CAD to buy gold is to buy a security that bears interest at the rate i_{CA} over the period that it takes to complete the transaction involving gold.[34] Thus, the importation of gold is profitable for Canadians iff $\frac{X_{CA}}{SX_{UK}} > 1 + i_{CA} + k$, where k is the proportional cost (cost per ounce of gold) of making the gold transaction. The cost k arises because there are shipping, insurance and time costs involved with importing or exporting gold. The spot exchange rate

$$S_{CA} = \frac{X_{CA}}{X_{UK}}\left(\frac{1}{1 + i_{CA} + k}\right)$$

is known as the Canadian gold import point. For spot exchange rates less than S_{CA} it is profitable for Canadians to import gold from the United Kingdom. Of course, when there are many countries on the gold standard, there is a gold import point for each pair.

Next, consider the question of when should UK citizens import gold from Canada. The British could take 1 pound sterling to the spot market, and get S CAD. They could then take the Canadian dollars to the Canadian Treasury and get $\frac{S}{x_{CA}}$ ounces of gold. They could ship this gold across the Atlantic Ocean, take it to the Bank of England, and get $X_{CA}\frac{S}{X_{UK}}$ pound sterling. Assume the British citizens also have the alternative of buying securities that bear interest rate i_{UK}. Then the transaction is profitable if $\frac{SX_{UK}}{X_{CA}} > 1 + i_{UK} + k$. The spot exchange rate

$$S_{UK} = \frac{X_{CA}}{X_{UK}}(1 + i_{UK} + k)$$

is known as the U.K. gold import point. For spot exchange rates greater than S_{UK} it is profitable for the British to import gold from Canada.

[33]Macmillan Committee on Finance and Industry (1997, 247).

[34]This example is much like that of the price-specie flow mechanism, except that instead of the alternatives being buying domestic goods versus foreign goods, the alternative is which capital investment to make.

Putting the two gold points together yields a condition for no gold flows to occur. The condition is that S satisfy[35]

$$\frac{X_{CA}}{X_{UK}}\left(\frac{1}{1+i_{CA}+k}\right) < S < \frac{X_{CA}}{X_{UK}}(1+i_{UK}+k). \tag{6}$$

[35]The "price" at which coins trade at the mints of different countries is called the mint ratio, which I denote as MR and define to be (monetary units of country j/monetary unit of country j'). For this example, MR is the price of CAD in terms of pounds sterling, or $MR = \frac{X_{CA}}{X_{UK}}$. With this notation, equation (6) can be written as

$$MR\left(\frac{1}{1+i_{CA}+k}\right) < S < MR(1+i_{UK}+k). \tag{5}$$

Appendix II: Data Sources

Prices

Belgium, Denmark, France, Germany, the Netherlands, Norway, Sweden, Switzerland, United Kingdom: http://eh.net/database/global-finance/. Prices are from worksheet "13. Prices." The prices in the original database are base 1913 = 100. I have rebased them to 1880 = 100.

Canada: Urquhart (1986) rebased to 1880 = 100.

United States: Officer and Williamson (2014) rebased to 1880 = 100.

Real output

Canada: Urquhart (1986) rebased to 1880 = 100.

France: Saint Marc (1983) rebased to 1880 = 100.

The Netherlands: computed from Data Archiving and Networked Services (2000) rebased to 1880 = 100.

Norway: Grytten (2004) rebased to 1880 = 100.

United Kingdom: Column A in worksheet "Real GDP" in the Data Annex to Hills, Thomas and Dimsdale (2010) rebased to 1880 = 100.

United States: Williamson (2014) rebased to 1880 = 100.

Exchange Rates

CAD/$: computed on an annual basis from Bank of Canada Archives (n.d.). The premium of the U.S. dollar against the Canadian dollar was computed using a par value of $1 per CAD.

£/$: Officer (2015). The premium of the U.S. dollar against the British pound was computed using a par value of $4.8665 per £.

FF/$: Computed from the British pound/French franc exchange rate from http://eh.net/databa finance/ worksheet "18. Exchange Rates" and the British pound/U.S. dollar exchange rate given above. The premium of the U.S. dollar against the French franc was computed using a par value of $0.193 per FF.

Gold

Stock of world gold obtained by adding annual production for 1876 - 1914 from Ridgway (1929, Table 3) to total world gold in 1875 from Soetbeer (1879, Table XIX), converted to troy ounces.